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# Modeling Dynamic Adjustment in a Multi-Output Framework

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A multi-output model framework to analyze the structure of the postwar period. The model's consistency with dynamic economic theory. Fluctuations in capital stocks, variable inputs, and outputs are explained by changing opportunity costs. Empirical results indicated that durable equipment, farm-produced durables, and family labor exhibited significant rigidity in adjustment as a response to exogenous shocks. The hypothesis that real estate was a variable input, surprisingly, could not be rejected. The univariate flexible accelerator hypothesis, which is widely maintained in most agricultural adjustment studies, is inconsistent with the data.

Keywords: Agricultural investment, dynamic duality, adjustment costs, multi-output technologies.

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## INTRODUCTION

In a dynamic agricultural economy, firms typically restructure their resource allocation decisions as a response to changing relative prices, so it is meaningful to investigate the adjustment process accompanying the revision of optimal production plans. An important feature of the economic climate faced by U.S. agricultural producers is temporal variation in relative prices of inputs and outputs. Price changes are induced sometimes by the operation of macroeconomic shocks. A variety of factors, including but not limited to, the influence of technical change and shifting consumer tastes sometimes works to create unstable relative prices. Resource allocation decisions under profit maximization are constantly being revised regardless of the source of temporal price variation. This study focuses on the formulation and revision of production plans in an economic environment characterized by changing opportunity costs.

The maintained structural hypotheses of U.S. agricultural production, namely adjustment costs and multi-output technologies, permit shortrun and longrun economic responses to diverge. Such a divergence explicitly recognizes the dynamic nature of agricultural input and output markets. Inputs and outputs may fail to adjust instantaneously to their desired longrun values. When this happens, input and output markets are in shortrun disequilibrium. Because this disequilibrium is unlikely to persist for long, actual values eventually coincide with longrun desired values when the adjustment pattern is stable. We examined two features of the adjustment problem. First, we identified the forces determining longrun equilibrium values of agricultural inputs and outputs. Opportunity costs must figure as prime candidates here. Second, the adjustment process involved in the transition from current to longrun equilibrium values is highlighted.

We integrated two important analytical hypotheses into a well-defined optimization problem with the explicit intent of deriving econometric equations. We then assessed the development of empirical supply, variable factor demand, and stock adjustment equations. Care is taken to ensure that these equations conform to a well-defined optimization problem. We specified a normalized quadratic value function. The maintained model is rich enough to include several nested structures as alternative hypotheses. We identified a rigorous hypothesis-testing procedure. Results of the preliminary empirical investigation involving the use of U.S. aggregate agriculture time series data spanning 1948-79 are contained in this report.



## ADJUSTMENT COSTS, MULTI-OUTPUT TECHNOLOGIES, AND U.S. AGRICULTURE

The adjustment cost hypothesis provides an appealing rationalization for the divergence of actual values from desired values of a production input. Proponents of this hypothesis argue that it is costly for decisionmakers to adjust rapidly stocks of production inputs to their longrun equilibrium values (Arrow, 1982; Penrose, 1959).<sup>1/</sup> If this is true, then decisionmakers have an incentive to adjust slowly rather than quickly to minimize the penalty associated with rapid adjustment. Slow adjustment of inputs implied by the adjustment-cost hypothesis provides the required bridge between shortrun and longrun economic analyses. This distinction is meaningless in the absence of adjustment costs. The firm can respond immediately to changing market conditions because rapid adjustment is not penalized.

A concrete example may illustrate this point further. Suppose that the relative price of corn increases. Under expectations of continued rising prices, this will stimulate longrun corn supply and, by derived demand theory, increase inputs used in the production of corn. When no impediments to adjustment exist, actual supply and input use match desired values instantaneously. We ruled out sluggish adjustment in this example because the firm has no incentive to adjust slowly in the absence of adjustment costs. The distinctions between shortrun and longrun supply and input demand response, therefore, are nonexistent. Purely static production models fail to integrate the stylized feature of lagged adjustment because they implicitly impose the stringent assumption of zero adjustment costs. So, we can reasonably maintain consideration of the adjustment-cost hypothesis to explain dynamic behavior in input and output markets.

While the adjustment-cost hypothesis contains a powerful rationalization for the prevalence of lags in economic response, it serves another useful purpose as well. This hypothesis has been used successfully to analyze aggregate investment behavior (Berndt and others, 1979). The hypothesis introduces a new dimension into conventional production economics problems, whereby the allocation decision of the firm involves concurrent choice of variable inputs, supply of outputs, and optimal investment. By including the investment decision with other decision variables, we have used this hypothesis to define a broader class of problems.

Some important distinctions merit mention to give specific meaning to the idea of adjustment costs. Adjustment costs can be internal or external. When the penalty charged for altering input stocks are pecuniary in nature, the costs are external. Nonpecuniary costs reckoned in terms of forgone output or variable factors are internal costs. Either of them could be a maintained hypothesis, although it is easy to establish that, from a modeling perspective, external costs are a special case of internal costs (Mortenson, 1973). The present study adopts internal adjustment costs for U.S. agriculture. Besides being the less restrictive hypothesis, this practice is consistent with the development of previous agricultural investment studies (Vasavada and Chambers, 1986). Examples of adjustment costs in agriculture include search costs, relocation costs, reorganization costs, and psychic costs.

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<sup>1/</sup> Sources cited in the text are listed in the References section at the end of this report.



Another important feature of the present study is the emphasis on multi-output technologies. Several justifications are available for utilizing this hypothesis. First, the data employed in estimation were highly aggregative in nature. Detailed data available on outputs could be gainfully utilized in the model specification. The multi-output specification was also flexible enough to test some structural hypotheses, such as consistency in aggregation and jointness. A single composite output measure precludes this possibility.

The dual maintained hypotheses of multi-output technologies and adjustment costs are integrated into the analysis by modifying the conventional production function. Let  $L$  denote the vector of variable inputs,  $K$  the vector of quasi-fixed inputs,  $I$  the vector of gross investments in quasi-fixed inputs, and  $Y$  the output vector. Each of these variables must be indexed with a time subscript. The time subscript is dropped in our analysis mainly to avoid tedious notation. Quasi-fixed inputs are fixed in the short run but variable in the long run. Quantities of variable inputs can freely be varied at all times. One way to represent the restrictions implied by technology is the modified multi-output transformation function,

$$\Phi(Y, L, K, I) = 0. \quad (1)$$

The inclusion of investment in the transformation function reflects adjustment costs and warrants some elaboration. To see how the inclusion of investment in  $\Phi(\cdot)$  is equivalent to imposing the adjustment-cost hypothesis, consider the derivative,  $fY_i/fI_j$ . An expression for this derivative is easy to obtain in terms of the derivatives of  $\Phi(\cdot)$  by total differentiation of equation (1). This derivative measures the marginal change in the  $i$ th output when the  $j$ th input stock is augmented or depleted. This derivative is exactly zero as changing the size of the  $j$ th input stock is not penalized in the absence of adjustment costs. However, in the presence of adjustment costs, this derivative is negative because investment in the  $j$ th input stock is penalized by a reduction in the  $i$ th output. Adjustment costs are being measured here in terms of forgone output and, hence, are internal. The specification (equation 1) proves to be a convenient method for including the dual maintained hypotheses of multi-output technologies and adjustment costs. These components can now be fused into a consistent theoretical framework to derive empirical econometric equations.

#### A DYNAMIC MULTI-OUTPUT MODEL FOR U.S. AGRICULTURE

At each point, the representative agricultural firm enjoys a stream of rents accruing to its stock of quasi-fixed inputs. The value of this stream is a measure of the value of the firm, when appropriately discounted. Optimal levels of variable inputs, investments, and output supply are solutions to the problem of maximizing the value of a representative agricultural firm. A hypothetical two-stage maximization problem illustrates this principle. The development described here is an extension of dynamic duality developed by Epstein (1981).

In the first stage, the firm is presumed to pick quantities of variable inputs and outputs. Let  $W$  represent the vector of variable input prices and  $P$  the vector of output prices. All prices are normalized arbitrarily by the first output price. The price of the first output is set to one and is



excluded from P. The shortrun normalized restricted profit function for the multi-output transformation function (1) is the solution to:

$$\pi(P,W,K,I) = \max_{Y,L} P'Y - W'L \text{ subject to } \Phi(.) = 0. \quad (2)$$

The notation ' denotes transposition. Adjustment costs impact on the short-run profitability of the representative firm. Any expansion or contraction of quasi-fixed input stocks is accompanied by a reduction in shortrun profits. The dual function  $\pi(.)$  inherits this property from the function  $\Phi(.)$  (Diewert, 1973). A duality relationship between  $\pi(.)$  and  $\Phi(.)$  is implied, subject to regularity conditions that the feasible input and output combinations define a closed, nonempty, and convex set. This duality causes  $\pi(.)$  to obey certain regularity conditions. These are:  $\pi(.)$  is linearly homogenous, monotonically increasing, and concave in K; homogenous of degree zero and convex in all prices; monotonically decreasing in variable input prices; and monotonically increasing in output prices. Standard duality arguments establish these results.

The second phase of the decision process involves optimal choice of quasi-fixed inputs by maximizing the discounted future stream of rents. Rents accruing to quasi-fixed inputs are obtained by subtracting total rental cost from shortrun variable profits. Some additional notation is necessary to aid in representing this problem concretely. Denote the vector of normalized unit rental prices of quasi-fixed inputs by q and the constant discount rate by  $\beta$ . Finally  $\epsilon$  is a proxy for the diagonalized matrix of constant depreciation rates. The firm solves:

$$J(P,W,q,K) = \max_I \int_0^{\infty} \exp(-\beta t) [\pi(.) - q'K]dt, \quad (3)$$

subject to the standard equations of motion  $dK = (I - \epsilon K)dt$  and the initial conditions  $K(0) = K_0$ . The equations of motion merely restate the standard formulation that gross investment is the sum of net investment and replacement investment. The assumption of geometric decay in the quasi-fixed input stock is implicit in this analysis. Justifications for this assumption are documented by Jorgenson (1974). The infinite horizon assumption may seem innocuous. This assumption is consistent with geometric decay of the capital stock maintained earlier. Besides, the decisionmaker only follows up on the optimal plan implied by equation (3) for the first time period. At the end of the first time period, equation (3) is solved again after updating the information set.  $J(.)$  is the optimal value of the firm.

The time subscript has been suppressed in the maximand, hiding an important issue in specification and estimation of dynamic production models, namely the formation of future price expectations. The values of  $(P,W,q)$  must be known with certainty either at the beginning of the planning period, or as expectations are formed about values at all future points in time. Otherwise, the maximand in equation (3) cannot be evaluated. Several approaches are available to tackle this problem. Prominent among these is the rational expectations view (Muth, 1961). Including this approach into the type of analysis proposed here is extremely difficult. So, we maintain the simplifying assumption that economic agents have static expectations. Static expectations essentially stipulate that current relative prices repeat themselves over the planning horizon.



The value function  $J(\cdot)$  inherits some properties from the now primal normalized restricted profit function  $\pi(\cdot)$  (Epstein, 1981). This follows from the duality relationship that given  $\pi(\cdot)$ , a corresponding  $J(\cdot)$  occurs and vice versa. The empirical analysis shows how this duality helps to obtain convenient closed-form expressions for variable input, investment, and output supply equations. These behavioral equations describe the relationship between optimal values of decision variables and opportunity costs, which is the main interest of this analysis. Exploiting duality results to develop estimating equations shows the distinction that equations so obtained can be integrated back into a well-defined value function. The strategy pursued here will closely parallel that adopted in static duality studies (see Diewert, 1984, for a comprehensive survey of this approach). First, a flexible form for a value function  $J(\cdot)$  is specified. The econometric equations are then defined in terms of derivatives of the value function.

#### A NORMALIZED QUADRATIC VALUE FUNCTION

Several choices for the value function  $J(P, W, q, K)$  are available. These choices are more fully described in Epstein (1981). A normalized quadratic second-order Taylor series expansion was chosen for this study. One reason for making this choice was that the implied variable input, investment demand, and output supply equations were linear in normalized prices. Both shortrun and longrun investment demand equations inherited this property. This functional form has been adopted in previous studies of aggregate agricultural investment behavior (Lopez, 1985; Vasavada and Chambers, 1986). Consider the parametric specification:

$$J = a_0 + [a_1 \ a_2 \ a_3 \ a_4] \begin{bmatrix} P \\ W \\ q \\ K \end{bmatrix} + [P' \ W' \ q' \ K'] \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{12} & A_{22} & A_{23} & A_{24} \\ A_{13} & A_{23} & A_{33} & A_{34} \\ A_{14} & A_{24} & A_{34} & A_{44} \end{bmatrix} \begin{bmatrix} P \\ W \\ q \\ K \end{bmatrix} \quad (4)$$

Note that  $a_0$  is a scalar;  $a_1, a_2, a_3$ , and  $a_4$  are appropriately dimensioned vectors. Likewise,  $A_{11}, A_{12}, \dots, A_{44}$  are appropriately dimensioned matrices. Equation 4 expresses a relationship between optimal value of a firm, opportunity costs, and quasi-fixed input stocks. We obtain econometric equations by noting that the Bellman equation corresponding to problem (3) is:

$$\beta J = \max \{ [\pi(P, W, q, K) - q'K] + J(I - \epsilon K) \}. \quad (5)$$

The Bellman equation (5) contains an important economic principle: at each point in time along the optimal path, the required rate of return implied by the subjective discount rate is the same as the actual objective rate of return. That is, the firm picks an optimal production plan involving choice of inputs and outputs that equate the two magnitudes.

The Bellman equation helps to express optimal decision variables in terms of first and second derivatives of the value function  $J(\cdot)$ . Application of the envelope theorem to (5) yields the equations:



$$\dot{K}^* = \frac{1}{q_k} \epsilon K = J_q [\beta J^{-1} + K], \quad (6a)$$

$$L^* = -\beta J_w + J_{wk} \dot{K}^*, \quad (6b)$$

$$Y^* = \beta J_p + J_{pk} \dot{K}^*. \quad (6c)$$

Lower case subscripts in (6a)-(6c) designate derivatives. For example,  $J_q$  is the vector of first partial derivatives of the value function with normalized rental prices of quasi-fixed inputs. We extended this convention to second derivatives and noted that  $J_{wk}$  signifies the subhessian matrix whose typical  $ij$  th element is  $\{fJ/fW_i fK_j\}$ . Equations (6a)-(6c) correspond to the dynamic analogue of Hotelling's lemma, which is widely used in applied static duality analysis (Young and others, 1985). Given the value function (equation 4), the optimal investment demand, variable input, and output supply equations can be expressed in terms of the first and second derivatives of the value function.

The structural model used in econometric estimation is derived by applying (equations 6a-6c) to the value function (equation 4). Equations in the structural model are:

$$\dot{K}^* = A_{34}^{-1} [\beta \{a_3 + A_{13}P + A_{23}W + A_{33}q + A_{34}K\} + K], \quad (7a)$$

$$L^* = -\beta [a_2 + A_{12}P + A_{22}W + A_{23}q + A_{24}K] + A_{24} \dot{K}^*, \quad (7b)$$

$$Y^* = -\beta [a_1 + A_{11}P + A_{12}W + A_{13}q + A_{14}K] + A_{14} \dot{K}^*. \quad (7c)$$

A closer look at the system of investment demand equations reveals some interesting information. Longrun, quasi-fixed input demand equations are obtained by setting net investment to zero and solving the implicit equations in (7a). We observed longrun input demands to be linear in normalized prices. Another feature shared by the equations in (7a) is that they define a multivariate flexible accelerator (MFA). The MFA was originally advanced to characterize a richer class of lag distributions than were provided by simple accelerator models (Nadiri and Rosen, 1969). The MFA always results when the matrix  $J_{pk}$  is a constant matrix.

We have stressed the relationship between longrun equilibrium values and impediments that prevented attainment of these values. The prevalence of adjustment costs ensures that complete adjustment to steady-state values does not occur instantaneously. This information is embodied in the net investment equations (7a). Several alternative models are nested within the maintained structural model and can be obtained by imposing simple parametric restrictions.

#### A HYPOTHESIS-TESTING PROCEDURE

The maintained structural model, consistent with a MFA lag distribution, is verified by rewriting equation (6a) as:

$$\dot{K}^* = M[K - \bar{K}], \quad (8)$$



where the matrix  $M$  equals  $\beta + J_{qk}$ , and the vector of steady-state input demands is  $K = -\beta J_q$ . All structural hypotheses relate to the crucial adjustment matrix  $M$ . When the matrix  $M$  is a diagonal matrix, we obtain the univariate flexible accelerator adjustment mechanism. This alternative model rules out interdependencies in adjustment between different inputs. For example, the adjustment of capital stock is unaffected by disequilibrium in labor markets. Previous agricultural investment studies have invoked the univariate flexible accelerator (Griliches, 1960; Penson and others, 1981). For this reason, testing this hypothesis was a useful exercise.

Another possibility lies in noting that, in the absence of adjustment-costs, inputs instantaneously adjust to desired levels. This is the same as the observation that the matrix  $-M$  in equation (8) is a unit matrix. When  $M$  is a unit matrix, actual investment equals desired investment, and no short run disequilibria can occur in input markets. Imposing this restriction helps to investigate the null hypothesis of no adjustment costs. The ability to confront the maintained hypothesis with observed data is yet another strength of the adjustment-cost model proposed in our investigation. A test for instantaneous input adjustment is also a test for the hypothesis that all production inputs are variable. Rejection of this hypothesis does not terminate the hypothesis-testing procedure.

Intuition suggests that this hypothesis might likely be rejected. The conclusion that all factors are not variable does not rule out the possibility that some inputs are variable. To test for the possibility that a single input, say the  $i$ th input is variable, we must impose the following parametric restrictions:

$$M_{ii} = -1, \text{ and } M_{ij} = 0 \quad \forall \quad i \neq j. \quad (9)$$

Each input can individually be tested by imposing equation (9), following the rejection of the hypothesis that all inputs are variable. The results obtained from this exercise will guide future analysts toward correctly specifying empirical production models. Investigations into rigid adjustment in input markets have a long and sometimes controversial history. The asset fixity hypothesis (Johnson and Quance, 1982) and attempts to test it (Chambers and Vasavada, 1983) have received some attention recently. A second advantage of our hypothesis-testing procedure follows from the empirical information obtained on the degree of asset fixity in U.S. agriculture. Table 1 summarizes structural hypotheses and implied parametric restrictions.

Before we discuss the empirical analysis, we must note the test statistic used to discriminate among alternative models. Several choices are available for this purpose. Prominent among these are Wald statistics, likelihood ratio statistics, and Lagrangian multiplier statistics. Our study used the likelihood ratio statistic. If  $\sigma$  denotes the ratio of values of likelihood functions for restricted and unrestricted models, then  $-2 \ln \sigma$  is distributed as a chi-square with degrees of freedom equal to the number of independent restrictions (Theil, 1971). This test is easy to apply and one that is often used in related studies.

Table 1--Hypotheses of interest and implied parametric restrictions

Hypothesis	Parametric restrictions*	Remarks
All production, inputs variable	$M_{11} = M_{22} = M_{33} = M_{44} = -1$ ; and $M_{12} = M_{13} = M_{14} = M_{21} = M_{23}$ $= M_{24} = M_{31} = M_{32} = M_{34}$ $= M_{41} = M_{42} = M_{43} = 0$	M is the negative of the unit matrix
Durable equipment variable matrix	$M_{11} = -1$ ; and $M_{21} = M_{31} = M_{41} = 0$	Modify first column of adjustment matrix
Real estate variable matrix	$M_{22} = -1$ ; and $M_{12} = M_{32} = M_{42} = 0$	Modify second column of adjustment matrix
Farm-produced durable variable	$M_{33} = -1$ ; and $M_{13} = M_{23} = M_{43} = 0$	Modify third column of adjustment matrix
Family labor variable	$M_{44} = 1$ ; and $M_{14} = M_{24} = M_{34} = 0$	Modify fourth column of adjustment matrix
Univariate flexible accelerator	$M_{12} = M_{13} = M_{14} =$ $M_{21} = M_{23} = M_{24} =$ $M_{41} = M_{42} = M_{43} =$ $M_{31} = M_{32} = M_{33} = 0$	M is a diagonal matrix

\*1 denotes durable equipment, 2 represents real estate, 3 stands for farm-produced durables, and 4 denotes family labor.

#### EMPIRICAL RESULTS

The empirical model is comprised of four quasi-fixed inputs, two variable inputs, and four outputs. Quasi-fixed inputs include durable equipment, real estate, family labor, and farm-produced durables. Hired labor and intermediate materials are variable inputs. Grains, livestock, dairy, and other field crops are the outputs. Data used in estimation are described in Ball (1985). Before proceeding to estimate the model, we appended a time trend to each equation, consistent with standard practice in empirical production models. The time trend is a proxy for biased technical change in U.S. agriculture. We assumed biased technical change to function as a shifter on the input



demand and output supply equations. A positive coefficient for the time-trend variable indicated input-using technical change in the input equations. A negative coefficient was consistent with input-saving technical change. The maintained structural model was recursive. We employed the method of iterative, nonlinear, seemingly unrelated regressions. Parametric estimates obtained by this method are asymptotically equivalent to maximum likelihood estimates at the point of convergence. This observation has significance to the hypothesis-testing procedure initiated at a later stage in the empirical analysis. All estimation was performed by using the TROLL package.

Table 2 contains estimated parameters of the adjustment matrix for maintained and accepted versions of the model. Adjustment coefficients provided information on the relative speed of adjustment to a divergence of actual from desired values. A change in relative prices induces a gap between actual and desired stocks, which is not rectified in the immediate time period. Durable equipment took a little over 3 years to adjust to desired values. This result can be explained in some cases by the observation that agricultural machinery cannot be deployed in other industries during periods of declines in prices of agricultural products. In an extreme case, when adjustment costs for this input are infinite, we cite a common example that once agricultural machinery is installed, it is set in place and cannot be disinvested in response to changing relative prices. A similar conclusion emerged for farm-produced durables.

However, family labor predicted longer adjustment lags. This input took over 4 years to adjust to a disequilibrium. Long lags in labor adjustment have been alluded to in agricultural economics literature (Baumgartner, 1965) and have been regarded as an important element of the farm problem. One possible explanation for rigid labor adjustment is the specific human capital embodied in farming as an occupation. When profitability of farming declines, farmers are unable to switch easily their labor skills to other occupations. This process takes significant retraining, and farmers may continue to remain in agriculture, at least in the short run, in anticipation of improved profits. The surprising result obtained from our model was that real estate stocks changed instantaneously to desired levels. No adjustment lags were prevalent for this input, confirming the hypothesis of zero adjustment costs.

Table 3 carries results of the hypothesis-testing procedure. The univariate flexible accelerator hypothesis was tested. A calculated likelihood ratio statistic of 173.51 exceeded the corresponding tabulated value of 32.62 for 16 degrees of freedom. This hypothesis was rejected. Rejection of the univariate flexible accelerator has been confirmed by previous empirical studies as well (Epstein and Denny, 1983). Adoption of this adjustment mechanism may lead to incorrect conclusions in studying agricultural input markets. We then determined whether all production inputs were variable. Again, the calculated likelihood ratio statistic exceeded the table value for 12 degrees of freedom, pointing out the prevalence of quasi-fixity in aggregate U.S. agriculture. Quasi-fixity may be viewed as a weak form of asset fixity. Our results confirm the notion of rigidity in input market adjustment.

The next step involved testing for quasi-fixity of individual inputs. The calculated statistic for durable equipment, farm-produced durables, and family labor were all higher than the table value of 13.70 for 4 degrees of freedom. Quasi-fixity of these inputs could not be rejected. Significant adjustment costs were apparently associated with changing the levels of

Table 2--Estimated parameters of adjustment matrix for maintained and accepted versions of model

Parameter*	Maintained model		Accepted model	
	Estimate	Std. error	Estimate	Std. error
M <sub>11</sub>	-0.3019	0.0574	-0.3064	0.0435
M <sub>12</sub>	.0137	.0459	0	0
M <sub>13</sub>	.3535	.0798	.3372	.0713
M <sub>14</sub>	.1125	.0222	.1124	.0189
M <sub>21</sub>	.9363	.1903	-1.1022	.1512
M <sub>22</sub>	.7350	.1514	-1.0000	0
M <sub>23</sub>	.8431	.2608	-1.0606	.2067
M <sub>24</sub>	.1499	.0737	.1757	.0672
M <sub>31</sub>	.1367	.1085	.0664	.0752
M <sub>32</sub>	.1159	.0766	0	0
M <sub>33</sub>	.3961	.1418	.3079	.1226
M <sub>34</sub>	.0557	.0365	.0646	.0328
M <sub>41</sub>	.1413	.1756	.0808	.1233
M <sub>42</sub>	.0070	.1363	0	0
M <sub>43</sub>	.5131	.2263	.4349	.1753
M <sub>44</sub>	.1707	.0599	.1536	.0615

\*1 denotes durable equipment, 2 denotes real estate, 3 stands for farm-produced durables, and 4 denotes family labor.

Table 3--Likelihood ratio statistics for hypothesis tests

Hypothesis	Likelihood ratio statistic	Degrees of freedom	Table value for chi-square
Univariate flexible accelerator	49.53	12	27.78
All production input variables	173.51	16	32.62
Durable equipment variable	66.00	4	13.70
Real estate variable	4.80	4	13.70
Farm-produced durable variable	26.60	4	13.70
Family labor variable	61.43	4	13.70



these inputs. The hypothesis that real estate was a variable input could not be rejected. The calculated statistic did not lie in the region of rejection. Adjustment costs did not influence smooth changes in the stocks of this input. Empirical evidence generated by the hypothesis-testing procedure confirm the prevalence of adjustment costs as significant contributing factors in preventing instantaneous adjustment to changing opportunity costs. Dynamic output adjustment was also implied by our estimates. Equation (7c) clearly implies that so long as at least one input is quasi-fixed, output adjustment is dynamic.

The accepted model also gave detailed information about the nature of biased technical change in aggregate U.S. agriculture. Among the quasi-fixed inputs, durable equipment exhibited factor-using technical change; farm-produced durables exhibited the opposite behavior, namely factor-saving technical change. Self-employed labor, like family labor, also diminished in quantity as a result of technical change. The other variable input, intermediate materials, increased due to the influence of technical change. Three of four outputs had positive coefficients for the time trend. The sole exception was the supply of dairy products, which had a negative coefficient on the time trend. The unlikely coefficient sign for the dairy sector may arise because the dairy sector is highly regulated in the United States, and the present model inadequately captures relevant structural features of the dairy industry. The only explanatory variables in the dairy supply equation are relative prices and a time trend within the present framework. Inclusion of other variables may rectify this problem. Based on these coefficient signs, technical change tended to reduce the supply of dairy products while increasing grain, other field crops, and livestock output. Our dynamic specification overwhelmingly supports the presence of biased technical change at the aggregate level, both in input and output markets.

The model satisfied the monotonicity restriction. All left-hand-side variables had positive predicted values when evaluated at the point estimates. Despite the large number (101) of parameters to be estimated, many parameters were statistically significant at conventional levels of significance. Roughly 65 percent of the parameters were statistically significant at the 5-percent level of significance. The estimated parameters were inconsistent with convexity of the value function, as dynamic duality would imply. However, failure of a model to conform to curvature restrictions is not limited to this study. Many studies that adopt the dual approach have failed on this front (Shumway, 1983). Another encouraging observation was that most versions of the model attained convergence in fewer than 200 iterations. Apparently the complex cross-equation restrictions and poor starting values did not render the estimation procedure an impossible task.

## CONCLUSIONS

We have summarized the results of an ongoing project involving identification of the appropriate production structure for aggregate U.S. agriculture. This goal can only be accomplished in a sequence of steps. We hope that each step will provide some new information about the structure of production in the U.S. agricultural economy and will be a guide to research. Our model suggests that quasi-fixed inputs adjust to their desired values in 3 to 5 years. Disequilibrium in input and output markets induced by con-



stantly changing opportunity costs are not rectified immediately but carry over to the next few time periods. A sharp point of difference among previous estimates is the high adjustment speeds predicted by the multi-output model. Comparable previous studies that adopt a single composite output predicted lags of up to 20 years for labor (Vasavada and Chambers, 1986). Shorter lags predicted by this model may be a consequence of changing the model specification.

Knowledge about speeds of adjustment helps policymakers in the design of stabilization policy. Policy instruments in U.S. agriculture are usually designed to distort market-based opportunity costs. These policies have the effect of creating disequilibrium in input and output markets. Model estimates suggest a few years are required before the intended output supply and input demand levels stabilize to their new longrun equilibrium values. Estimated parameters can be used to develop shortrun and longrun price elasticities. While such an exercise is not difficult to perform, we relegated it to a later and more detailed investigation.

Future investigations must concentrate on improving model specification. Two important issues need to be addressed. The first issue relates to the specification of nonstatic expectations. The static expectations assumption, while convenient for empirical analysis, is unduly restrictive. Incorporating expectations into dynamic models is not an easy task. However, some improvement can be made on the existing model. The second issue relates to the imposition of curvature restrictions on the value function. Violation of curvature restrictions is a matter of some concern because the estimated model no longer obeys the properties stipulated by theory. Convexity constraints can be imposed by a method proposed by Lau (1978) and implemented by Ball (1988).





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